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LARGE-ARRAY SIGNAL AND NOISE ANALYSIS

Special Scientific Report No. 18

K-LINE SPECTRAL ANALYSIS OF LASA SHORT-PERIOD SUMMER NOISE

Prepared by

Frank H. Binder, Program Manager
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TEXAS INSTRUMENTS INCORPORATED
Science Services Division
P.O. Box 5621
Dallas, Texas 75222

Contract No. AF 33(657)-16678

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D.C. 20333

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
ARPA Order No. 599
AFTAC Project No. VT/6707

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ABSTRACT

This report discusses some additional applications of K-line spectra to the LASA short-period noise analysis. Two summer noise samples were processed to complement the work performed previously on eight winter noise samples. In addition, an experiment was conducted to determine if significantly better results could be obtained using 21 min of noise instead of 7 min to estimate the statistics.

The principal conclusions follow.

- Summer noise appears to be quite similar to winter noise at LASA
- Except at the microseismic peak, any processing results (gains) very probably can be extrapolated across seasons
- Using the long noise sample did not give more interpretable wavenumber spectra

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SECTION I

INTRODUCTION

The K-line spectral estimate technique was applied to two additional noise samples recorded during the summer months of 1966. These noise samples were recorded starting at 06:48 on 12 May 1966 and at 16:20 on 2 July 1966.

These noise samples were processed to determine possible seasonal variations in the short-period noise field. LASA Special Report 6 describes in detail the results obtained from eight noise samples recorded between October 1965 and April 1966.*

*Texas Instruments Incorporated, 1967: Analysis of Subarray Wavenumber Spectra, Large-Array Signal and Noise Analysis Spec. Rpt. 6, Contract AF 33(657)-16678, 30 Sept.

SECTION II

DESCRIPTION OF THE K-LINE WAVENUMBER SPECTRA

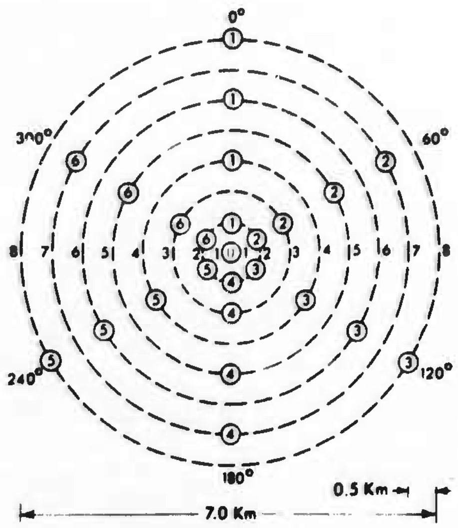
K-line spectra were computed at the F1 and F4 subarrays for the 12 May noise sample and at the F4 subarray for the 2 July noise sample. Figure II-1 shows the large array and subarray geometry during this time period.

The 1-dimensional wavenumber spectra are physically interpreted as projections of 2-dimensional power-density spectra onto axes which are parallel to the arms of a LASA subarray (Figure II-1). These spectra give the power density of the ambient seismic noise as a function of its apparent wavenumber along each of the array's arms.

The basic input for calculating each of the 1-dimensional spectra is the crosspower matrix $\Phi_{ij}(f)$, where f is the frequency and i and j range over the seismometers of each arm of the array (Figure II-1). The crosspower matrices were obtained by transforming the 4096-point time traces ($\Delta t = 0.1$ sec) using the Cooley-Tukey algorithm and smoothing the weighted crossproducts of the Fourier transform outputs over a 0.1-Hz frequency interval (41 basic frequency points).

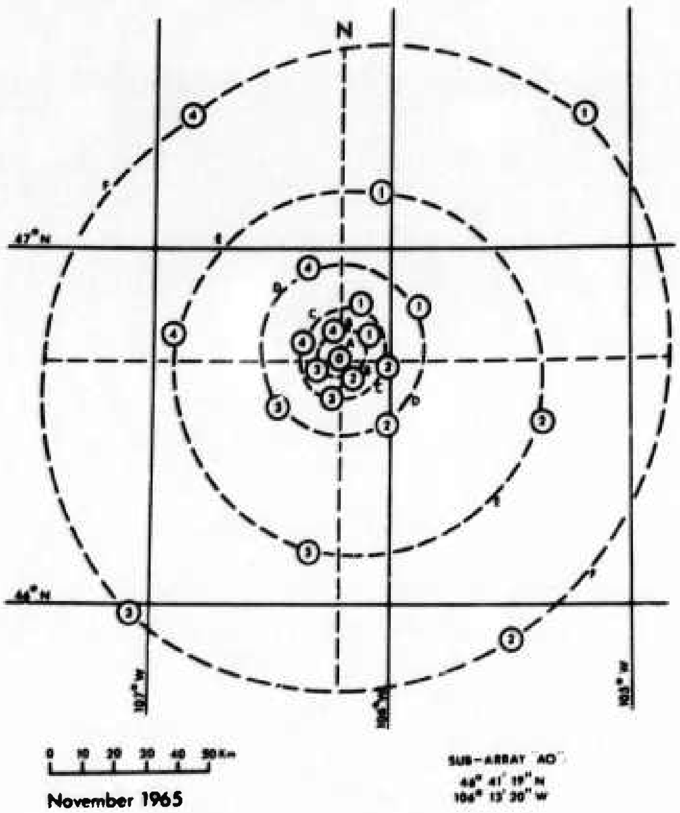
K-line wavenumber spectra are calculated in increments of 0.1 Hz at 10 frequencies starting with 0.2 Hz. The spectra are shown in Figures II-2 through II-4.

Each line of the array has a wavenumber power-density spectrum and an integrated wavenumber power-density function for each frequency. The power-density spectrum and the integrated density function are included in the same plot to save space. Wavenumber spectra are plotted in decibels vs wavenumber in cycles/kilometer. The left vertical axis is marked in 5-db increments, with the 0-db level indicating the average value of the spectrum.



STANDARD
SUBARRAY

NOTE:
Seismometer No. 10 Is 500' Deep
Seismometers 21-65 Are 200' Deep



LASA

Figure II-1. LASA Standard Subarray

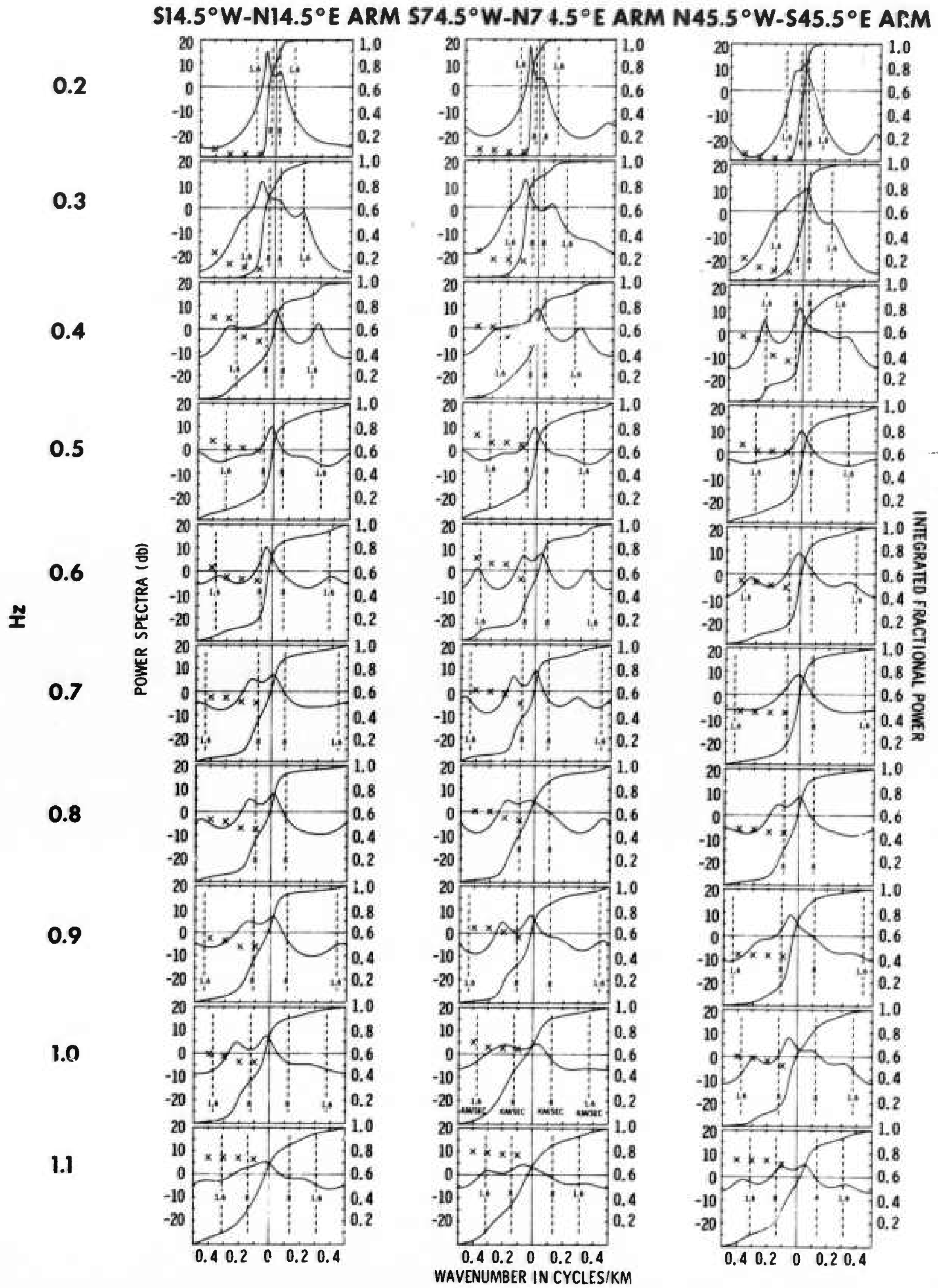


Figure II-2. Wavenumber and Integrated Spectra for Subarray F1, 12 May 1966

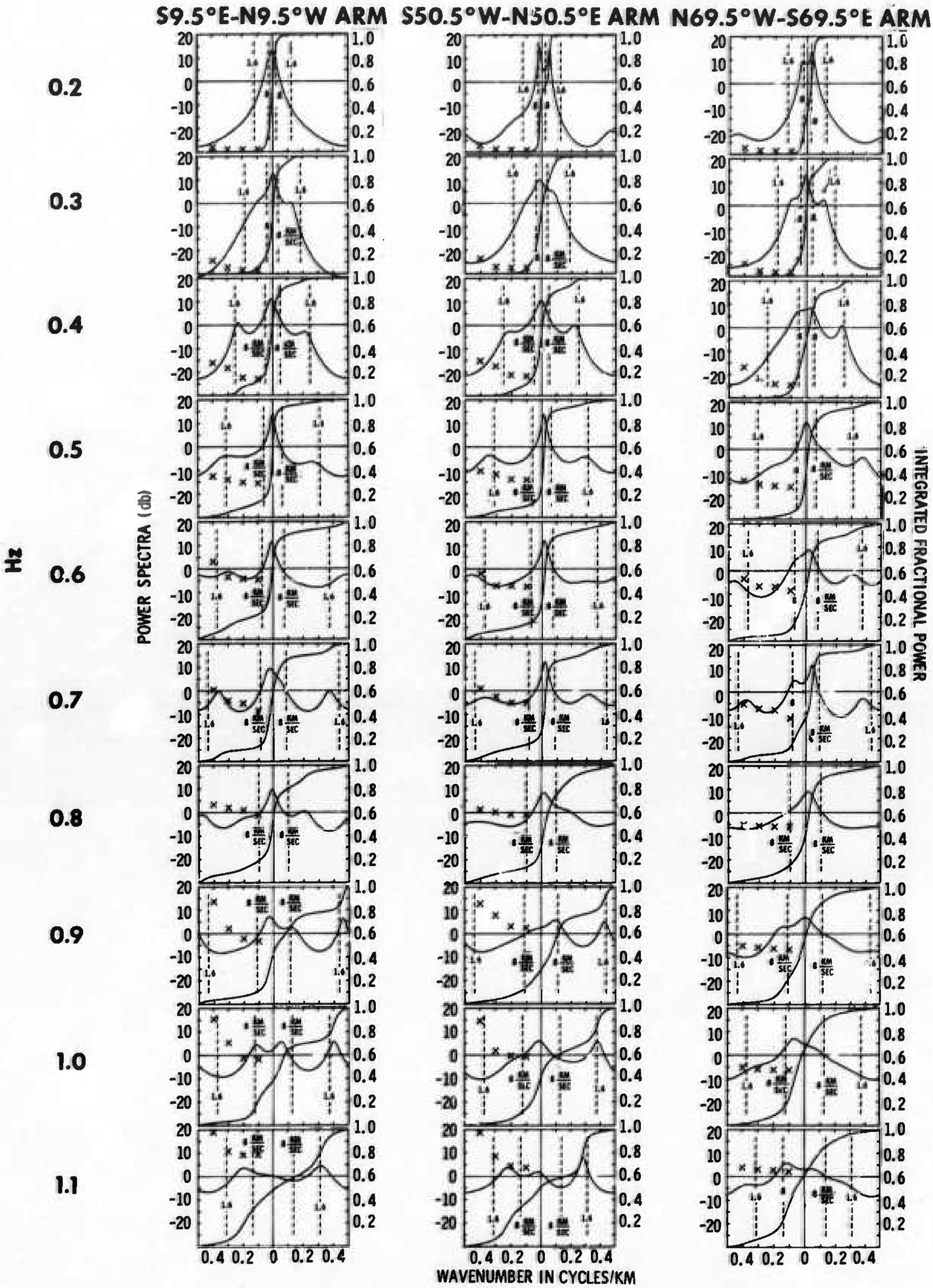


Figure II-3. Wavenumber and Integrated Spectra for Subarray F4, 12 May 1966

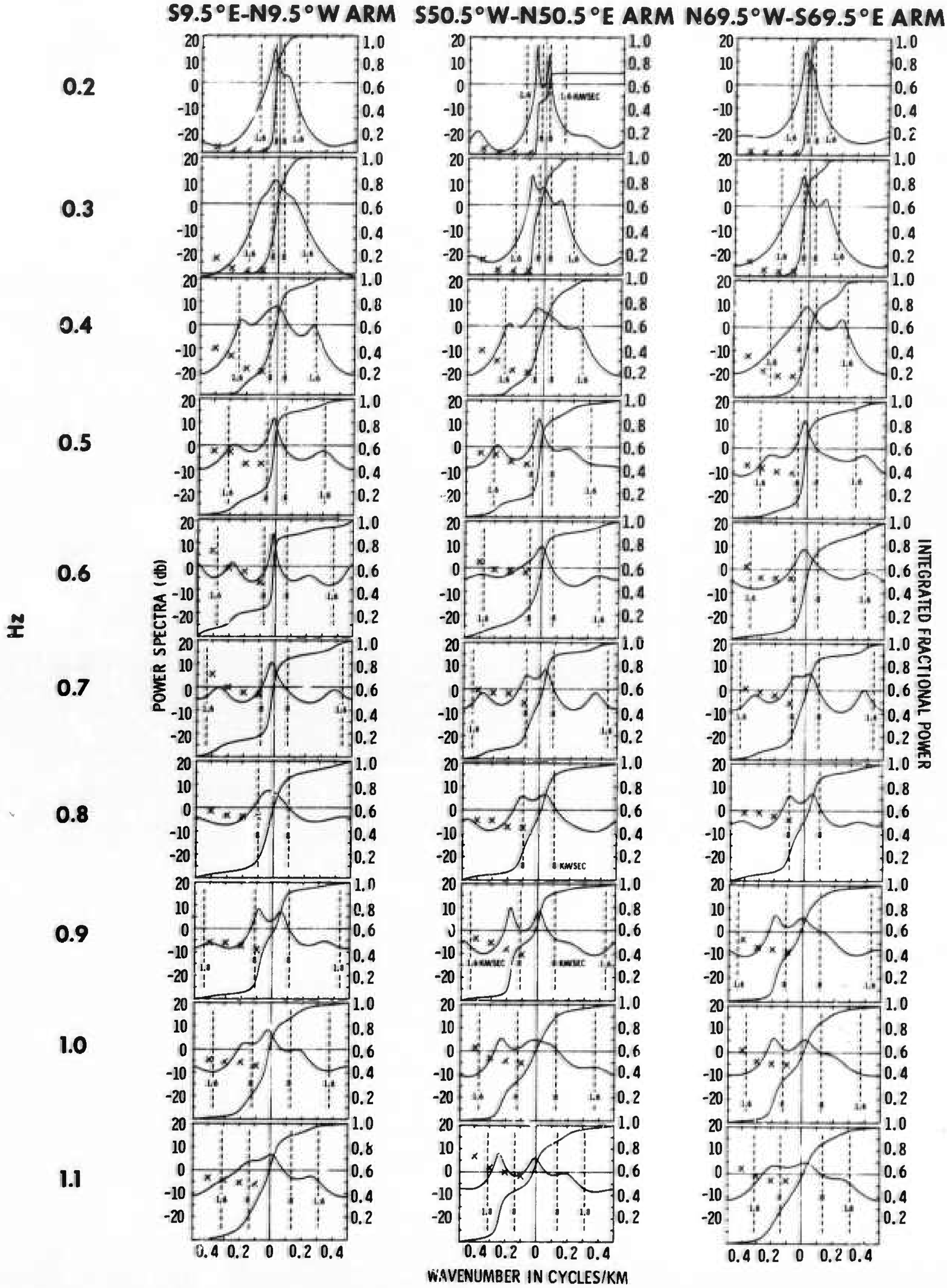


Figure II-4. Wavenumber and Integrated Spectra for Subarray F4, 2 July 1966

The normalized, integrated wavenumber power-density function is

$$\int_{-k}^{x} P(x)dx, \text{ with } \int_{-k}^{k} P(x)dx = 1$$

where P(x) is the wavenumber power-density spectrum and k is the foldover wavenumber. The foldover wavenumber is 1/2 times the average spacing of the equidistant seismometers along the arm of the array. This function has been plotted in fractional power vs wavenumber in cycles/kilometer. The right vertical axis is marked from 0.0 to 1.0 in increments of 0.1. These integrated spectra provide a method of measuring the amount of power in any velocity or wavenumber band.

In these wavenumber plots, the solid vertical line at the center of the plot (at k = 0) represents infinite apparent velocity along the arm of the array. On either side of this line are dashed lines representing velocities of 8.0 km/sec and 1.6 km/sec. These velocities are approximately the minimum apparent velocities for P-wave and Rayleigh-wave noise when the noise propagation is in line with an arm.

The velocity of 1.6 km/sec is the approximate fundamental surface-mode velocity in the frequency range 0.3 Hz <f < 1.0 Hz. The Rayleigh-wave velocity lines (1.6 km/sec) correspond to the edge velocity of the plots at 0.8 Hz. At higher frequencies, the velocity lines appear in their aliased position.

The third function contained in each plot is a discrete function denoted by small x's. These x's show the fractional power that is unpredictable when attempts are made to predict the next seismometer in line from a line of seismometers. In particular, the first x from the right

is the fractional mean-square-error in predicting one seismometer ahead (1.0 km) using four seismometers in a line. The first x from the left shows the prediction error using only one seismometer. The right vertical axis, marked from 0.0 to 1.0 in increments of 0.1, is used to determine the prediction error corresponding to each x.

A more detailed discussion of the K-line spectral technique has been published previously.*

*Texas Instruments Incorporated, 1967: Analysis of K-Line Wavenumber Spectra from the TFO Long-Noise Sample, Array Research Spec. Rpt. 23, Contract AF 33(657)-12747, 28 Feb.

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SECTION III

ANALYSIS OF K-LINE SPECTRA

Figure III-1 shows the smoothed power spectra by phase for the 12 May 1966 noise sample. These spectra have been estimated by interpreting the intersection pattern in the K-plane of the peaks in the K-line spectra (Figures II-2, II-3) and integrating the power in the appropriate peaks.

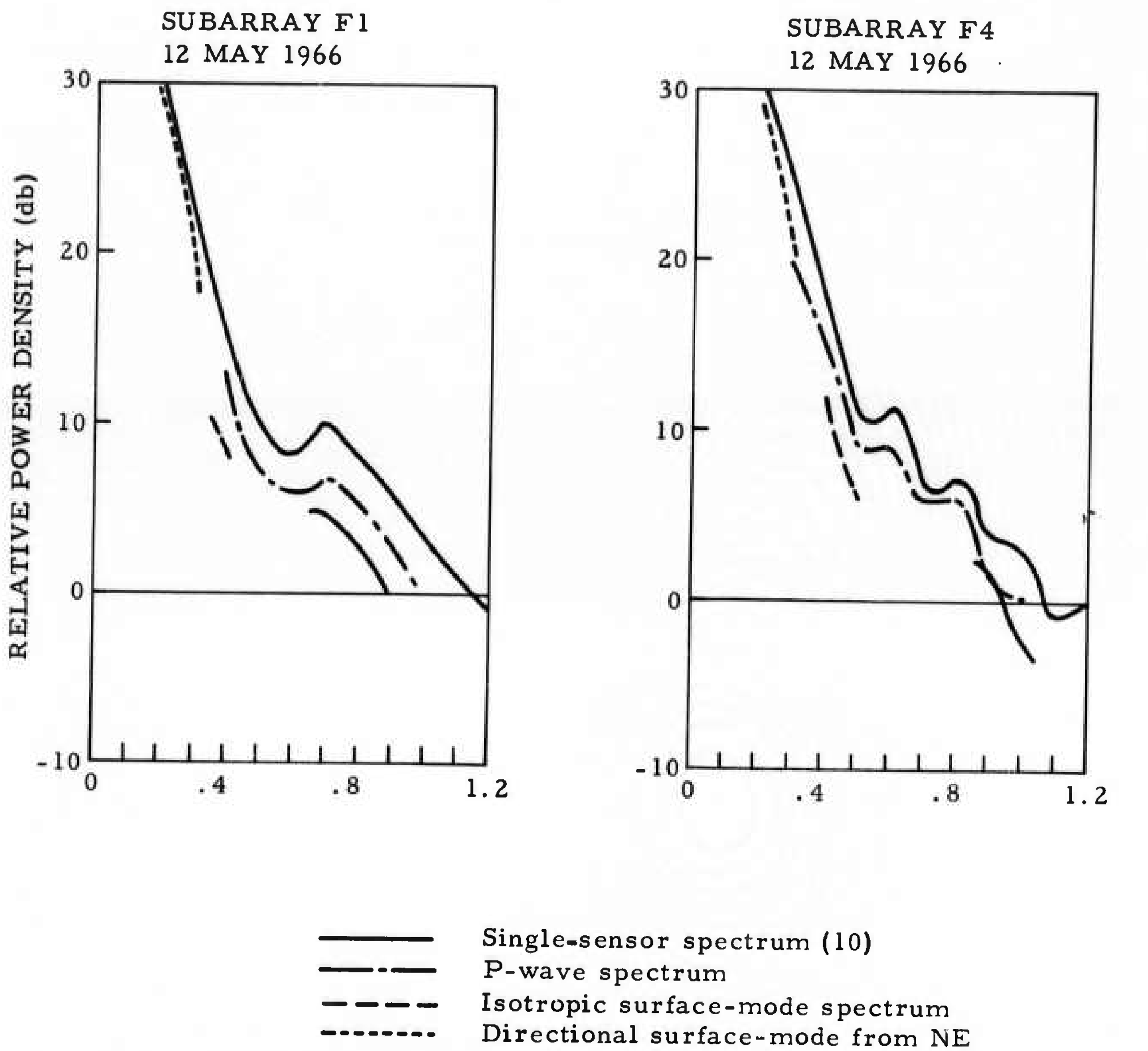

Figure III-1. Smoothed Power Spectra, Subarray F4, 12 May 1966

The low-frequency end of the spectrum is comprised almost entirely of a directional surface mode. This mode had a velocity of 3.2 km/sec from N55°E for subarray F4 and 2.9 km/sec from N41E at the F1 subarray. This mode was essentially bandlimited to frequencies of 0.3 Hz or less. At these low frequencies, estimating phase velocity accurately with a 7-km array is difficult.

The velocity about fits the second-order normal mode for a LASA crustal model.* In this frequency range, no directional energy with the velocity of the fundamental mode has been observed at LASA.

As indicated by Figure III-1, the microseismic peak is very strong on 12 May. The source of this seismic noise is evident from the wind-wave height chart shown in Figure III-2. This wave height chart was made about 5-1/2 hr after the 12 May noise sample was recorded. It shows strong wave activity along the coast of Newfoundland on a N50°E-to-N65°E bearing from LASA.

Almost all of the winter noise samples studied showed a similar directional surface-mode source near 0.2 Hz. Its azimuth varied from N42° to N83°E. The microseismic peak of this 12 May noise sample has the same characteristics as a typical winter sample.

P-wave noise is dominant between 0.4 and 1.0 Hz for the 12 May noise sample, which also is observed in the winter noise samples studied. The subarray K-line spectra give no indication of consistent directional P-wave noise.

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*Texas Instruments Incorporated, 1967: Continuation of Basic Research in Crustal Studies, Final Rpt., Contract AF 49(638)-1588, 15 July.

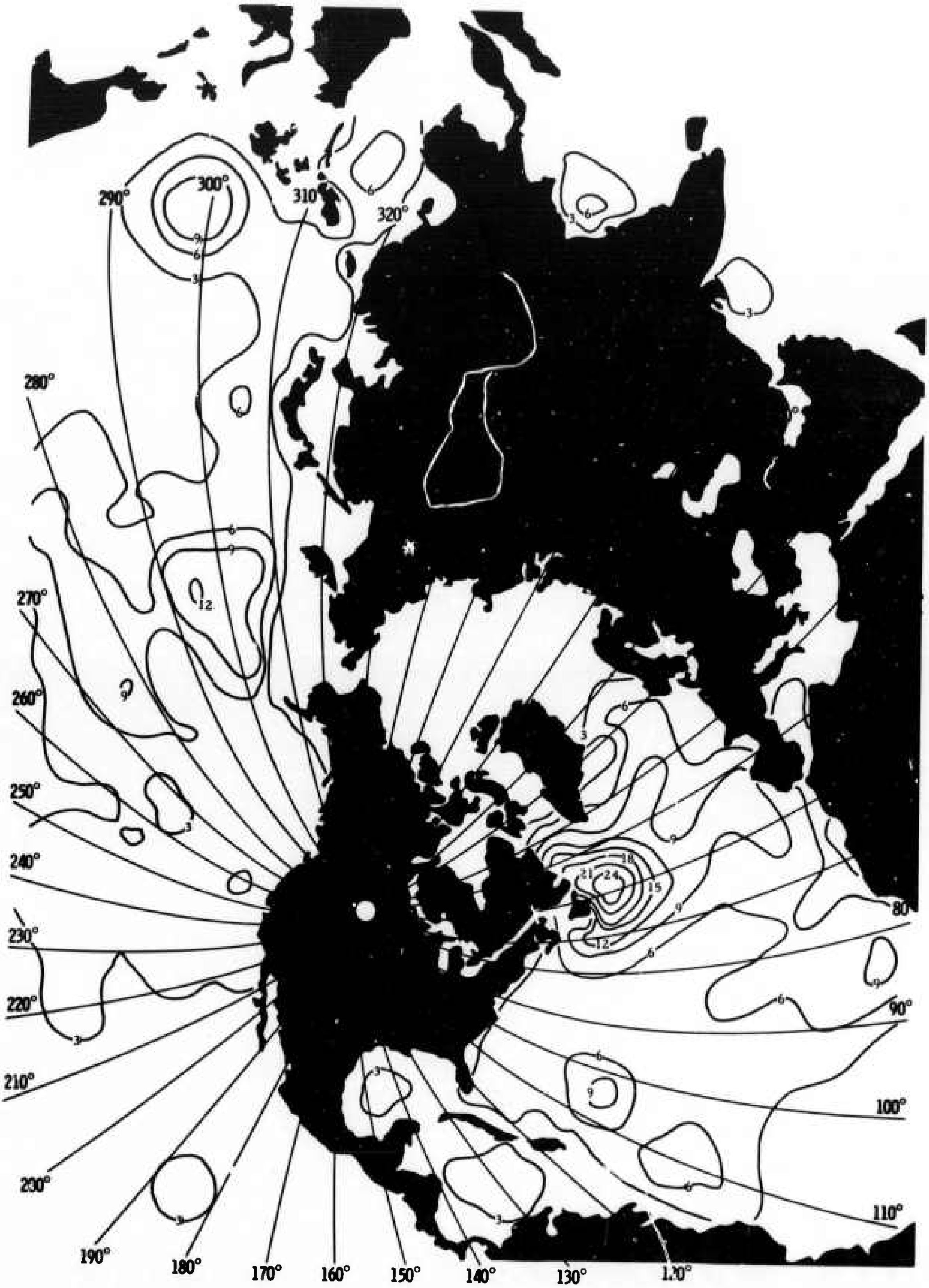

Figure III-2. Wind-Wave Height Chart for 1200 Hr on 12 May 1966

There are indications of isotropic Rayleigh-mode noise at the velocity of the fundamental Rayleigh mode in the 0.4- to 0.5-Hz range. This energy is identified by shoulders, or peaks, on the K-line at about 1.6 km/sec on each arm. By integrating the power in the shoulders of the K-line spectra, the power in this phase was estimated conservatively, for a small amount of this power is distributed throughout the region in wavenumber corresponding to -1.6 km/sec to +1.6 km/sec. A more detailed discussion of the K-line spectra generated by isotropic noise has been published.*

Isotropic surface-mode noise also was present in all the winter noise samples and generally could be identified in the band between 0.4 and 0.7 Hz.

In the 0.7- to 1.0-Hz frequency band, low-velocity directional energy ($v \approx 4.5$ km/sec) from the northeast is indicated. This mode has a velocity varying from about 4.2 km/sec to 4.5 km/sec and is characterized by large triangles of error when projecting the K-line peaks into the K-plane, possibly suggesting a diffuse source region. Directional energy with these same characteristics also was present in all the winter noise samples studied.

Overall, the 12 May 1966 noise sample appears to have the same general characteristics as the winter (October to April) noise samples previously studied.

Figure III-3 shows the smoothed power spectra by phase for the 2 July 1966 noise sample. Again, these spectra were estimated by interpreting the intersection pattern in the K-plane of the peaks in the K-line spectra and integrating the power in the appropriate peaks on the K-line spectra.

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*Op cit, Array Research Spec. Rpt. 23.

At 0.2 Hz, the 2 July noise energy is about 50-percent P-wave energy. A surface-mode peak from S62°W at 3.9 km/sec also is indicated. (This surface mode does not appear at 0.3 Hz.) The small size of the array precludes very exact measurement of phase velocity at 0.2 Hz.

This noise sample does not show the low-frequency directional surface-mode energy from the northeast which was almost always present in the winter noise samples.

Figure III-4 shows the wave height chart for sea conditions about 4-1/2 hr before recording the 2 July noise sample. This map indicates quiet conditions near North America. Based on this map, low microseism activity would be expected. This is confirmed by the fact that 50-percent of the energy at 0.2 Hz can be attributed to P-wave noise.

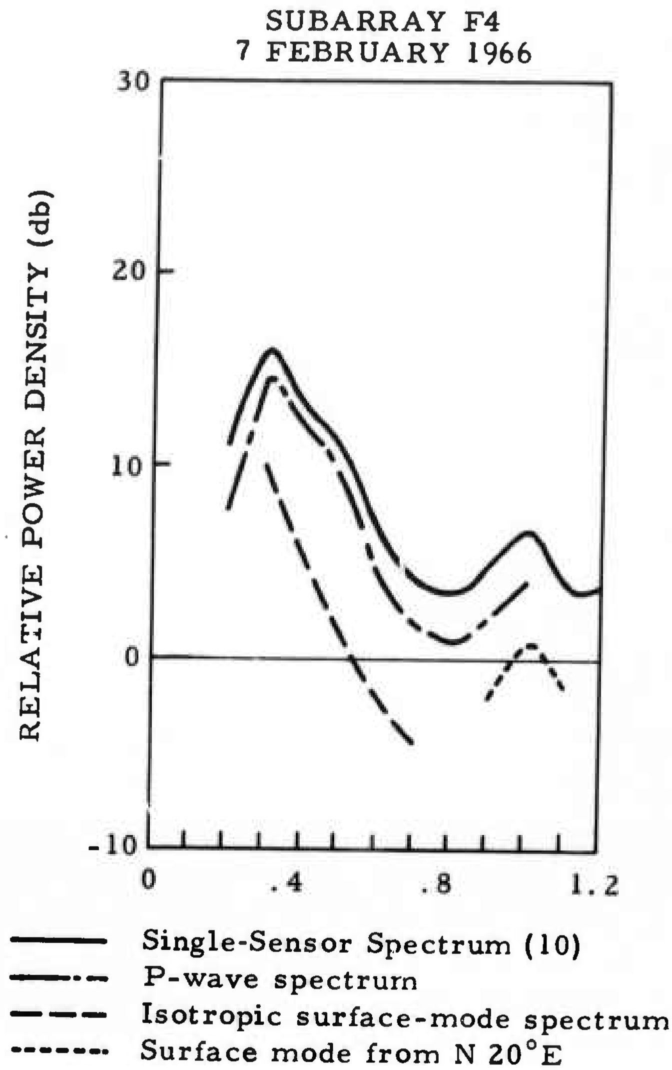

Figure III-3. Smoothed Power Spectra, Subarray F4, 2 July 1966

For the 2 July noise sample, P-wave noise dominates the energy spectrum between 0.2 and 1.0 Hz, suggesting that summer noise may be even richer in P-wave energy than the winter noise. This result is not unexpected, since the North Atlantic and the North Pacific are much quieter during the summer months.

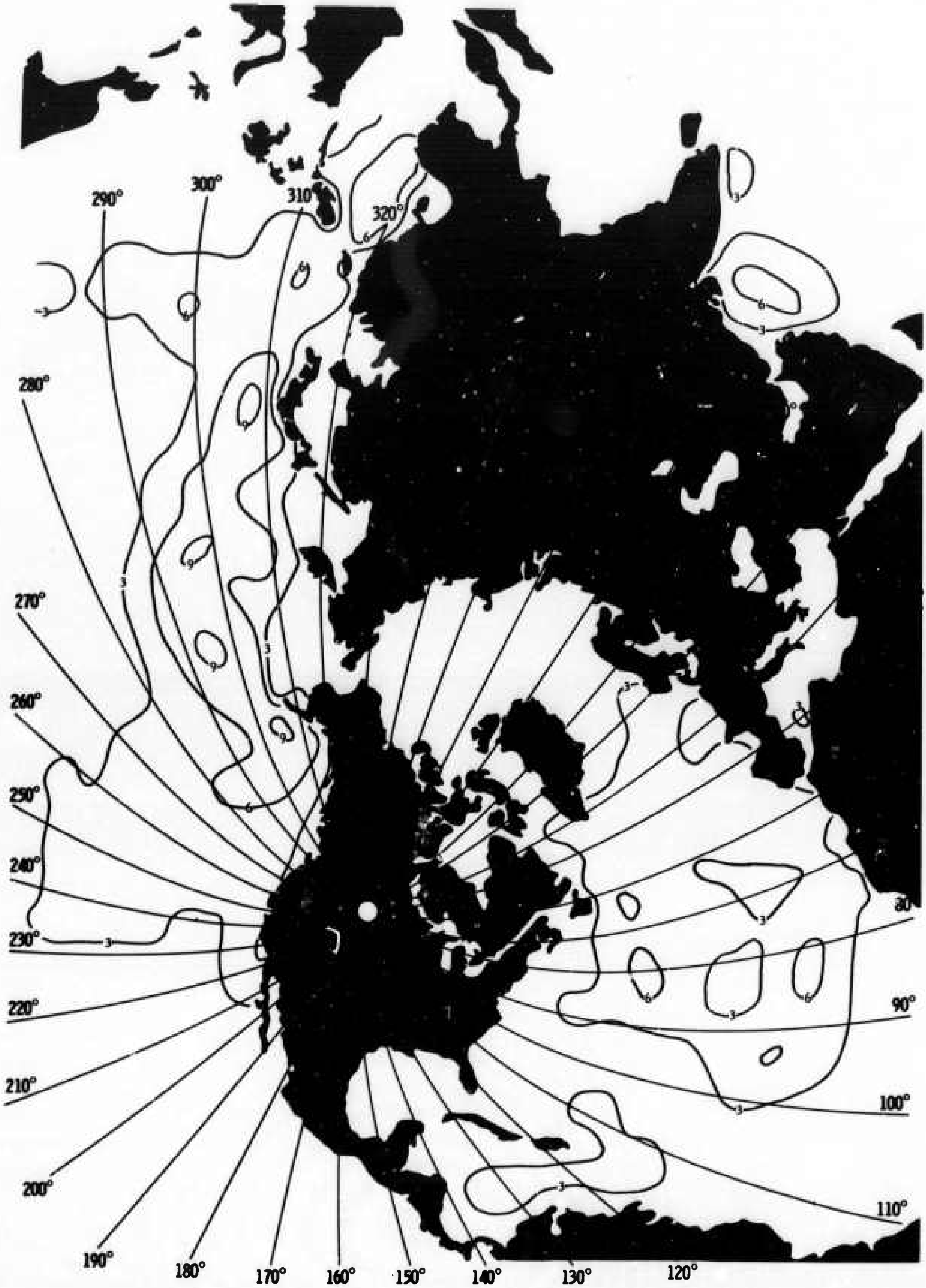

Figure III-4. Wind-Wave Height Chart for 1200 Hr on 2 July 1966

Isotropic surface-mode noise is indicated in the 0.3- to 0.5-Hz band. This velocity appears to be about 2.4 km/sec at 0.3 Hz, falling to about 1.6 km/sec at 0.4 Hz. This isotropic surface-mode energy represents 1/4 or less of the total spectrum.

Between 0.9 and 1.1 Hz, there is a well-defined peak corresponding to energy from N20°E to N25°E with a velocity of 1.3 to 1.4 km/sec. A similar peak was also present at the F4 subarray on some of the winter noise samples, but came from a somewhat different azimuth.* This energy is interpreted as surface-mode energy generated by wave activity on the nearby Fort Peck Reservoir. Subarray F4 is the subarray closest to the reservoir (about 60 km).

In conclusion, the two summer noise samples studied are generally very similar to the winter noise samples previously studied. The 12 May noise sample appears to be similar to a typical winter noise sample. The 2 July noise sample differs mainly in that there is no low-frequency surface mode from the northeast and that the spectrum is slightly richer in P-wave energy than the typical winter noise sample.

The P-wave spectrum often may be within 3 db or less of the total spectrum in the 0.2- to 1.0-Hz band. For the winter noise samples, the mantle P-wave energy was generally less than 3.0 db below the total noise spectrum in the 0.3- to 0.6-Hz frequency range. Between 0.6 and 1.1 Hz, the P-wave spectrum usually was 3.0 to 5.0 db below the total spectrum.

Except at the microseism peak (0.2 to 0.3 Hz), the processing results probably can be reasonably projected across all seasons at the LASA site.

*Ibid.

SECTION IV

K-LINE SPECTRA FROM A LONG-NOISE SAMPLE

It was suggested in a previous report* that the LASA K-line spectra might be improved by using a longer noise sample to form the spectral matrices.

To test this hypothesis, a few K-line spectra were generated from statistics gathered from three back-to-back noise tapes recorded on 29 April 1966. These were compared with the K-line spectra obtained from only one noise tape. There were no important changes.

In both cases, the spectral matrices were smoothed over a 0.1-Hz interval; this represents about 123 independent frequency vectors for the long-noise sample, while such an interval contains 41 independent frequency increments for the shorter noise sample.

Figure IV-1 shows the K-line for all three arms of subarray F4 calculated both ways. These are at 0.7-, 8.0-, 0.9-, and 1.0-Hz frequencies. As can be seen, the spectra are very similar. In general, after considering the triangles of intersection of the spectral peaks, a 7-min sample appears sufficient to calculate the K-line spectra.

*Op cit, LASA Spec. Rpt. 6.

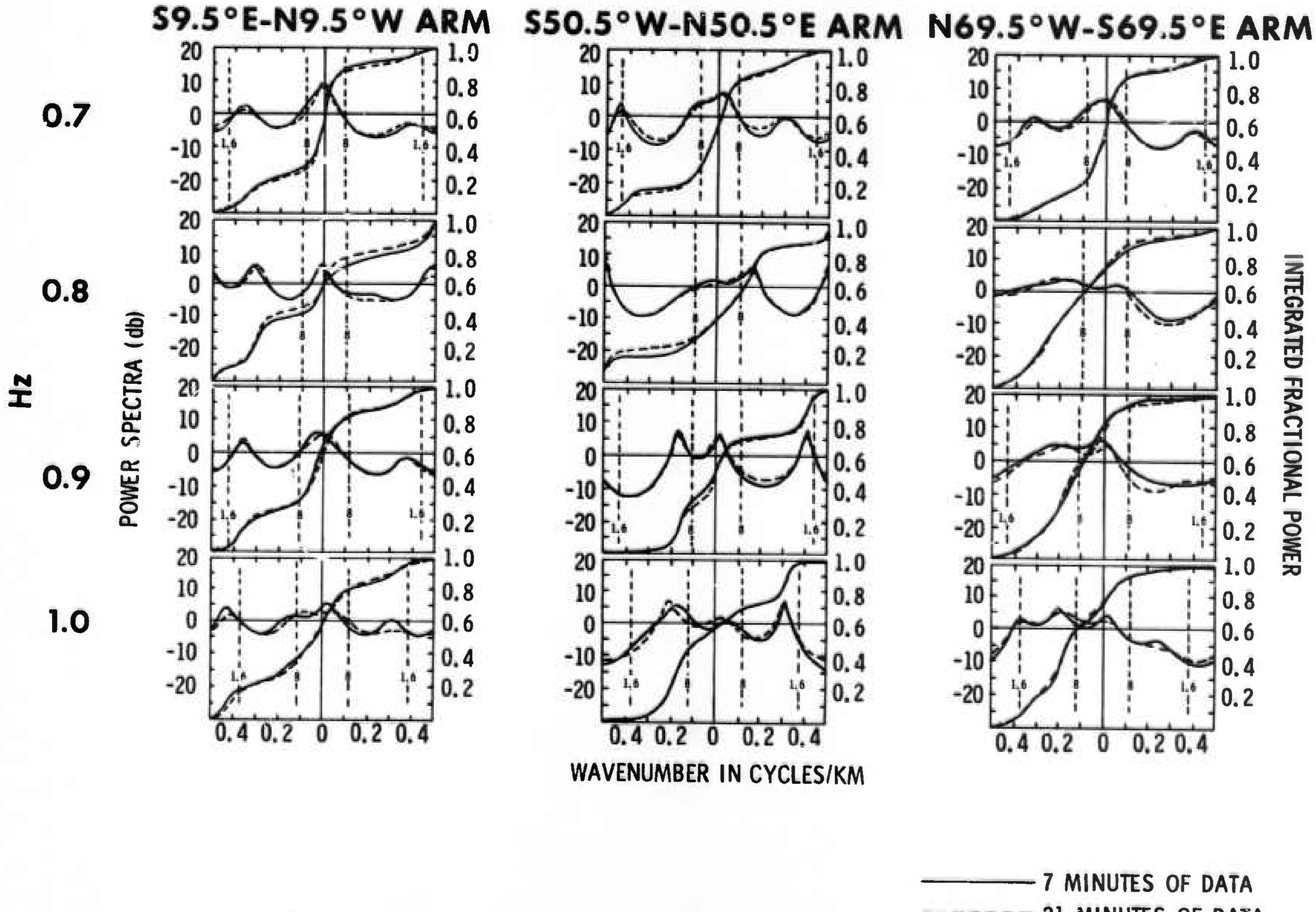

Figure IV-1. Wavenumber and Integrated Spectra Calculated Using 21 Min and 7 Min of Data, Subarray F4, 29 April 1966

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